Network Systems Science & Advanced Computing

Biocomplexity Institute & Initiative

University of Virginia

Estimation of COVID-19 Impact in Virginia

July 1st, 2020

(data current to June 30th)

Biocomplexity Institute Technical report: TR 2020-083

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Who We Are

- Biocomplexity Institute at the University of Virginia
  - Using big data and simulations to understand massively interactive systems and solve societal problems
- Over 20 years of crafting and analyzing infectious disease models
  - Pandemic response for Influenza, Ebola, Zika, and others

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Overview

- **Goal**: Understand impact of COVID-19 mitigations in Virginia
- **Approach:**
  - Calibrate explanatory mechanistic model to observed cases
  - Project infections through the end of summer
  - Consider a range of possible mitigation effects in "what-if" scenarios
- **Outcomes:**
  - Ill, Confirmed, Hospitalized, ICU, Ventilated, Death
  - Geographic spread over time, case counts, healthcare burdens

Key Takeaways

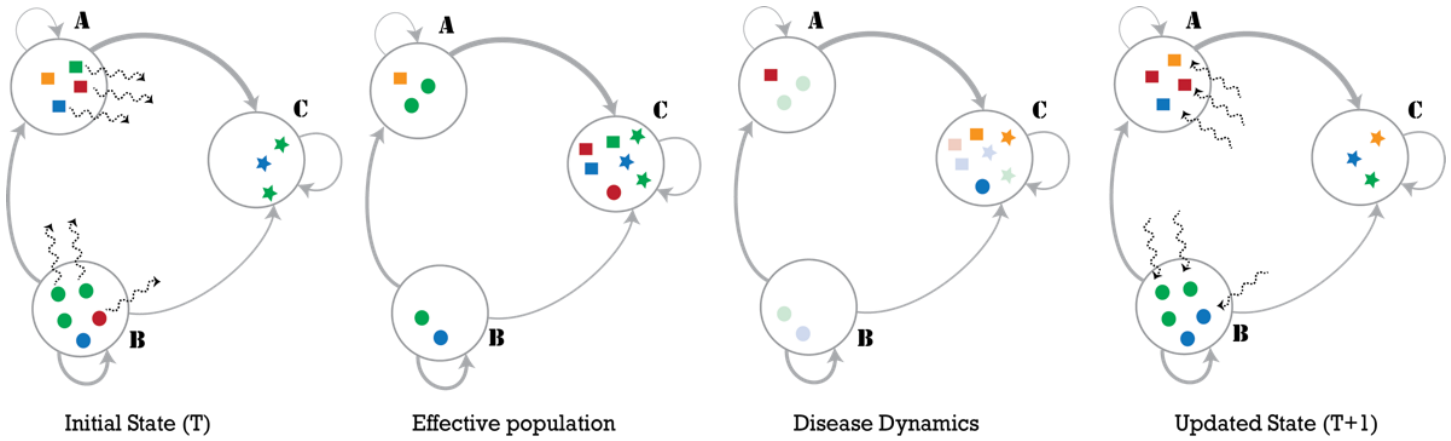
Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

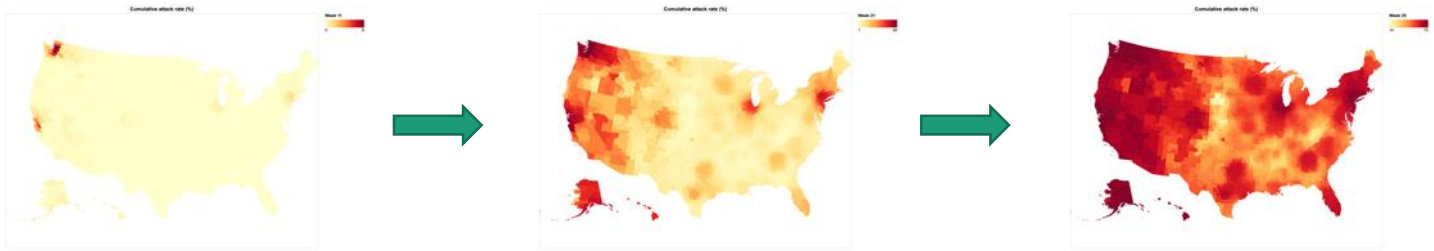
- **Virginia continues to maintain control as many areas of the country are entering a period of resurgence, however, there are signs of growth as some health districts have increased activity.**
- Model updates this week:
  - Added a scenario showing a potential resurgence of cases
  - Identified “Best fitting” scenarios district by district which match their recent trends and added a combined state level “Best Fit” scenario representing this combination
  - Updated additional analyses to inform restructuring of model for next phase of epidemic
- Other states showing rapid rise following relaxation of social distancing with limited control measures.
- The situation is changing rapidly. Models will be updated regularly.

Model Configuration and Data Analysis

Simulation Engine – PatchSim

- Metapopulation model
  - Represents each population and its interactions as a single patch
  - 133 patches for Virginia counties and independent cities
- Extended SEIR disease representation
  - Includes asymptomatic infections and treatments
- Mitigations affect both disease dynamics and population interactions
- Runs fast on high-performance computers
  - Ideal for calibration and optimization





Venkatramanan, Srinivasan, et al. "Optimizing spatial allocation of seasonal influenza vaccine under temporal constraints." *PLoS Computational Biology* 15.9 (2019): e1007111.

Model Configuration

- **Transmission:** Parameters are calibrated to the observed case counts
  - **Reproductive number:** 2.1 - 2.3
  - **Infectious period** (time of infectiousness before full isolation): 3.3 to 5 days
- **Initial infections:** Start infections from confirmed cases by county
  - Timing and location based on onset of illness from VDH data
  - Assume 15% detection rate, so one confirmed case becomes ~7 initial infections
- **Mitigations:** Intensity of social distancing rebound and control sustaining mitigations into the future are unknowable, thus explored through 5 scenarios

Mitigation Scenarios: Rebound Intensity x Detection

Pause from Social Distancing: Began on March 15th

- Lifted on May 15th (61 days), with two-week delay (75 days) for select counties*
- **Intensity**: Social distancing pauses and significantly reduces case growth, this level varies by VDH Health District and is fit through an analysis of growth rate during the Pause

Intensity of Rebound:

- **Steady:** Intensity of effective mixing remains steady from Pause as infection control practices moderate increased interactions
- **Light:** Effective mixing returns to 1/6th of pre-pandemic levels
- **Full Rebound**: Interactions return completely (100%) to pre-pandemic levels, as a reference

Tracing and Isolation: Increased Testing Capacity coupled with infection control measures can limit the period of infectiousness without isolation

- **Better Detection**: Observed relative reductions in days from onset to diagnosis applied to infectious period (30% and then 45%) and remain stable into future for projections

* Select counties as mentioned by recent releases from Governor Northam's office
https://www.governor.virginia.gov/newsroom/all-releases/2020/may/headline-856741-en.html
https://www.governor.virginia.gov/newsroom/all-releases/2020/may/headline-856796-en.html

Potential Future Surge Scenario

Resurgence: Several other states are experiencing a resurgence in cases

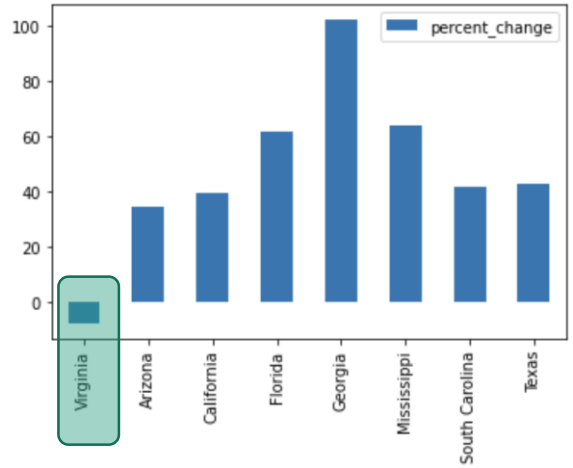
- Most relaxed social distancing 4-6 weeks prior to the surge in cases
- Timing remains uncertain, this projection uses a 5 week delay before increase in cases

Intensity of Surge:

- Difficult to anticipate, if control measures (testing & tracing, face coverings, etc.) remain in place this will dampen surge
- Measure an average R of 1.45 in late June for 7 most affected states, a 47% increase
- We assume Virginia continues "better detecting" cases, but experiences 50% increase in transmissions (more interactions, reduced social distancing and face coverings)

Surge Projection: 5 weeks from now, July 1st, 50% increase in transmissibility but better detection remains

Percent Change in Transmission
(mid May to late June)



Virginia has net decline between these periods

Five Mitigation Scenarios

Scenario	Rebound Intensity	Better Detection	Name	Description
1	Light	No	Light	Light Rebound, Detection same
2	Steady	No	Steady	Steady Interactions, Detection same
3	Light	Yes	Light – BetterDetection	Light Rebound, Detection improved
4	Steady	Yes	Steady – BetterDetection	Steady Interactions, Detection improved
5	Full	No	Full Rebound	Return to No mitigation

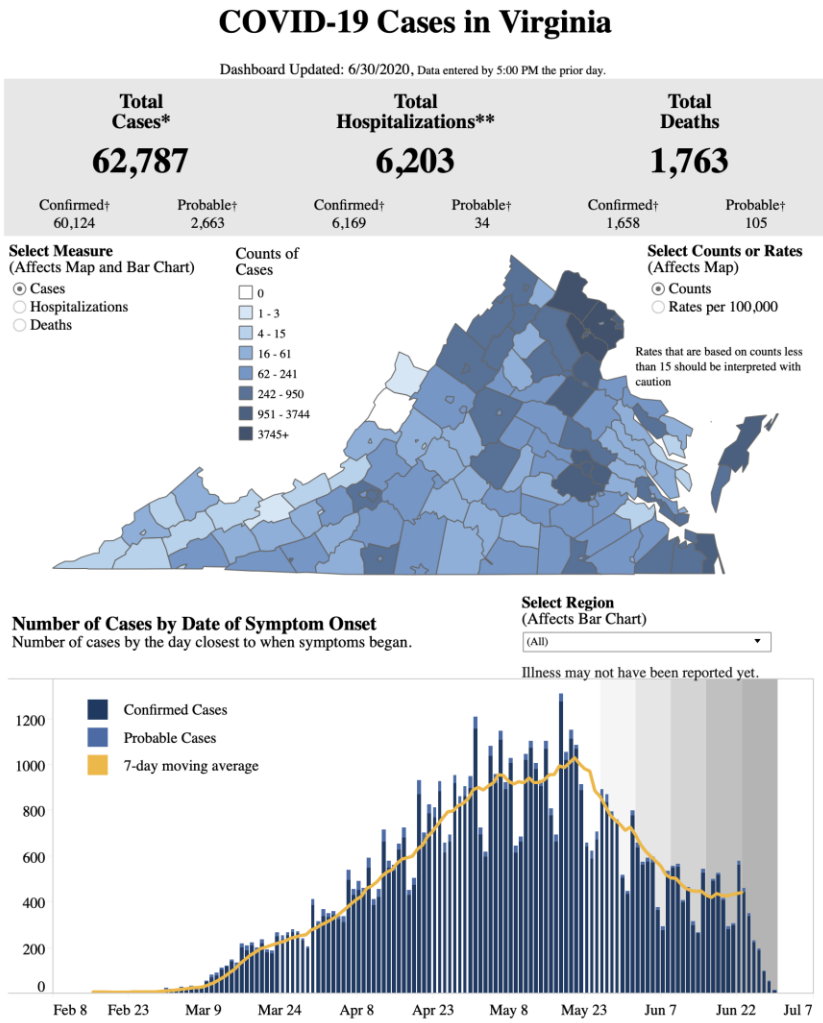
Full Model Parameters

	Parameter	Values	Description
Transmission	Transmissibility (R_0)[1]	2.2 [2.1 – 2.3]	Reproductive number
	Incubation period[1]	5 days	Time from infection to infectious
	Infectious period[1]	3.3 - 5 days	Duration of infectiousness
	Infection detection rate[3]	15%	1 confirmed case becomes ~7 initial infections
	Percent asymptomatic[1]	50%	Infected individuals that don't exhibit symptoms
Resources	Onset to hospitalization[1]	5 days	Time from symptoms to hospitalization
	Hospitalization to ventilation[1]	3 days	Time from hospitalization to ventilation
	Duration hospitalized	8 days	Time spent in the hospital [4]
	Duration ventilated[2]	14 days	Time spent on a ventilator
	Percent hospitalized[1]	5.5% (~20% of confirmed)	Symptomatic individuals becoming hospitalized
	Percent in ICU[1]	20%	Hospitalized patients that require ICU
	Percent ventilated[1]	70%	ICU patients requiring ventilation
	Percent Fatality	1.35%	Symptomatic individuals who die

1 CDC COVID-19 Modeling Team. "Best Guess" scenario. Planning Parameters for COVID-19 Outbreak Scenarios. Version: 2020-03-31.
2 Up-to-date. COVID-19 Critical Care Issues. https://www.uptodate.com/contents/coronavirus-disease-2019-covid-19-critical-care-issues?source=related_link (Accessed 13APRIL2020)
3 Li et al., *Science* 16 Mar 2020:eabb3221 https://science.sciencemag.org/content/early/2020/03/24/science.abb3221 (Accessed 13APRIL2020)
4 Personal communications, UVA Health and Sentara (~500 VA based COVID patients)

Calibration Approach

- **Data:**
  - County level case counts by date of onset (from VDH)
  - Confirmed cases for model fitting
- **Model:** PatchSim initialized with disease parameter ranges from literature
- **Calibration:** fit model to observed data
  - Search transmissibility and duration of infectiousness
  - Markov Chain Monte Carlo (MCMC) particle filtering finds best fits while capturing uncertainty in parameter estimates
- **Spatial Adjustments:** VDH districts grouped to 3 tiers of growth during the Pause, with similarly scaled reductions then applied to the groups of districts
- **Project:** future cases and outcomes using the trained particles

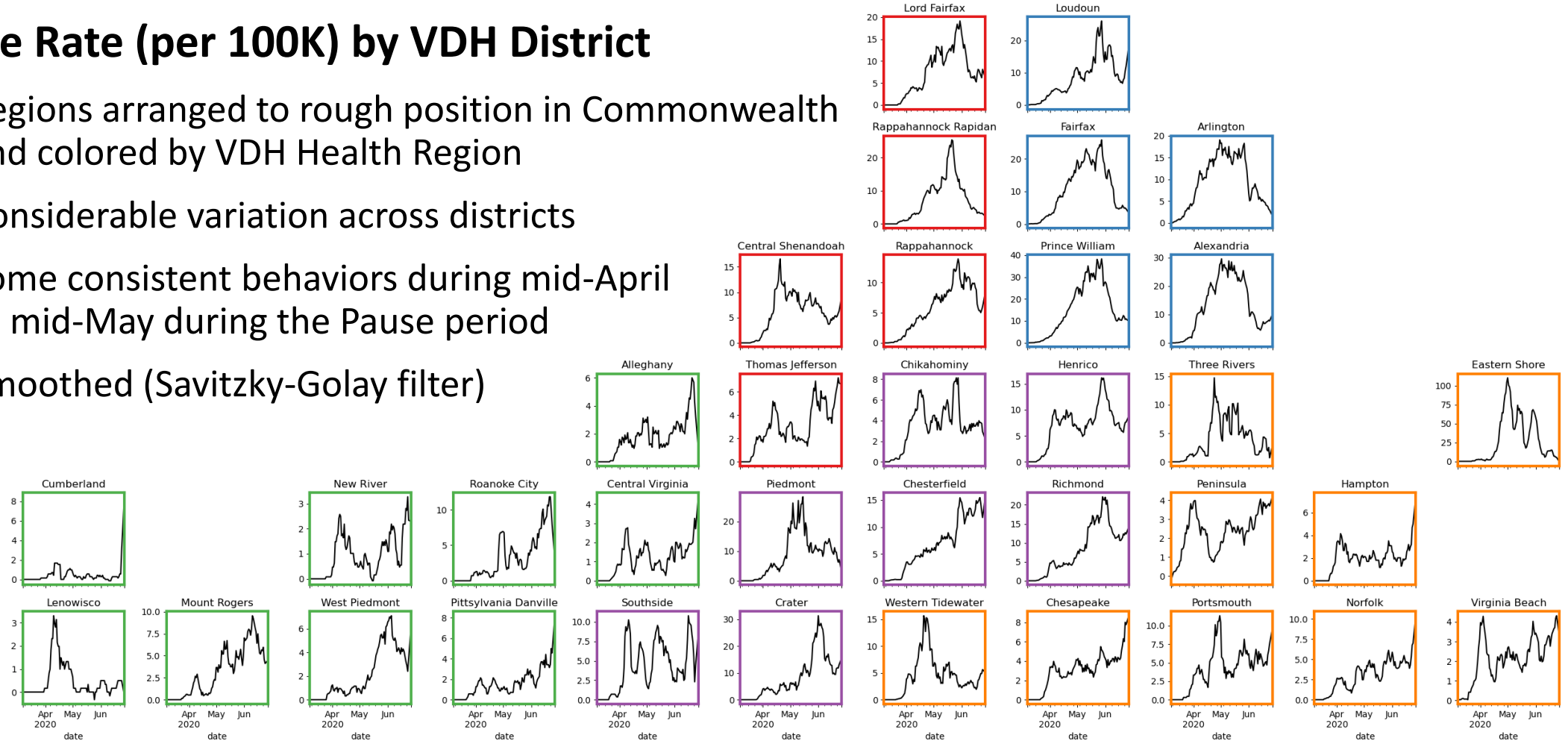


Accessed 9pm June 30, 2020
https://www.vdh.virginia.gov/coronavirus/

Spatial Adjustments at District Level

Case Rate (per 100K) by VDH District

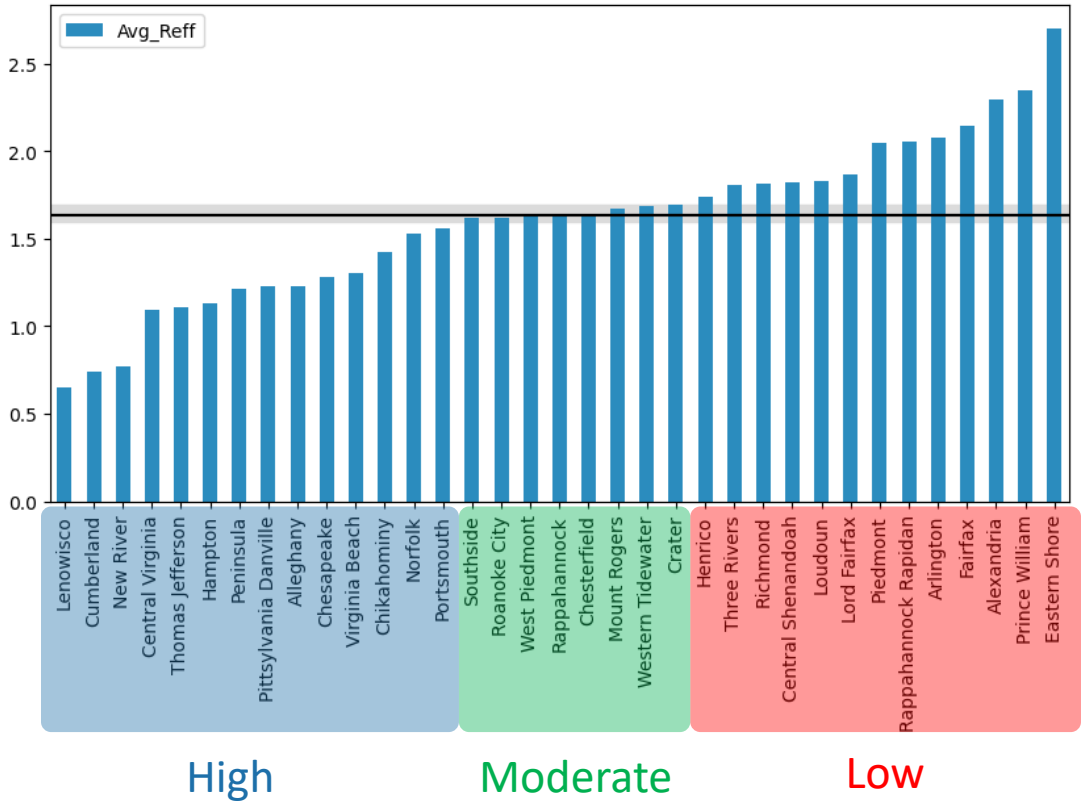
- Regions arranged to rough position in Commonwealth and colored by VDH Health Region
- Considerable variation across districts
- Some consistent behaviors during mid-April to mid-May during the Pause period
- Smoothed (Savitzky-Golay filter)



Spatial Adjustments at District Level

Adjustments based on Growth during Pause

- Group districts by their mean growth from mid-April to mid-May (using model based R_{eff})
- Assign reductions during Pause, and beyond, to members of these groups
- Low reduction = 40%
- Moderate reduction = 45% (previous level)
- High reduction = 55%



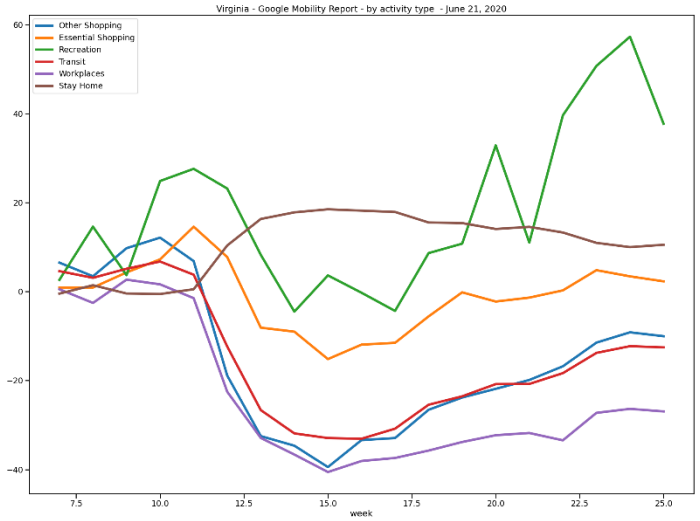
Impact of Interventions

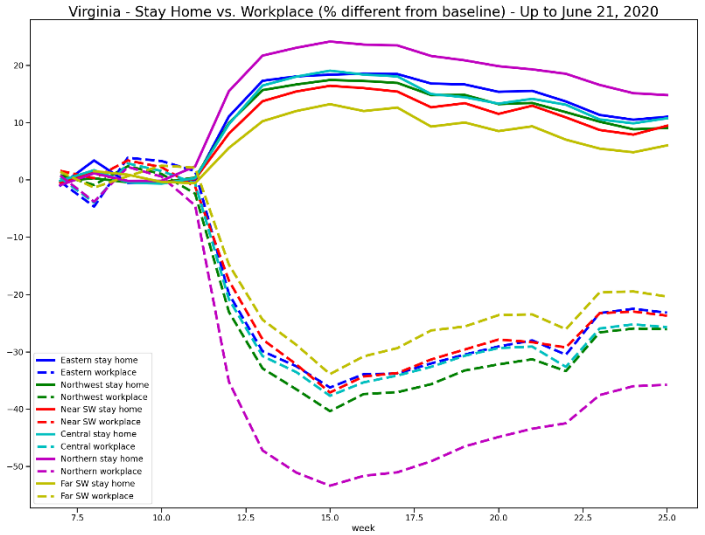
Estimating Effects of Social Distancing

Mobility data shows pause mid-March, slow rebound starting in May

Google Mobility data shows continued slow rebound
(as of June 14th)
https://www.google.com/covid19/mobility/

- Regional levels of Stay at home vs. Workplace
- 35% reduction of those staying at home, very slow and stable reductions
- Other activities show vaster increases with grocery / retail nearly back to baseline
- Parks and recreation show significant increase



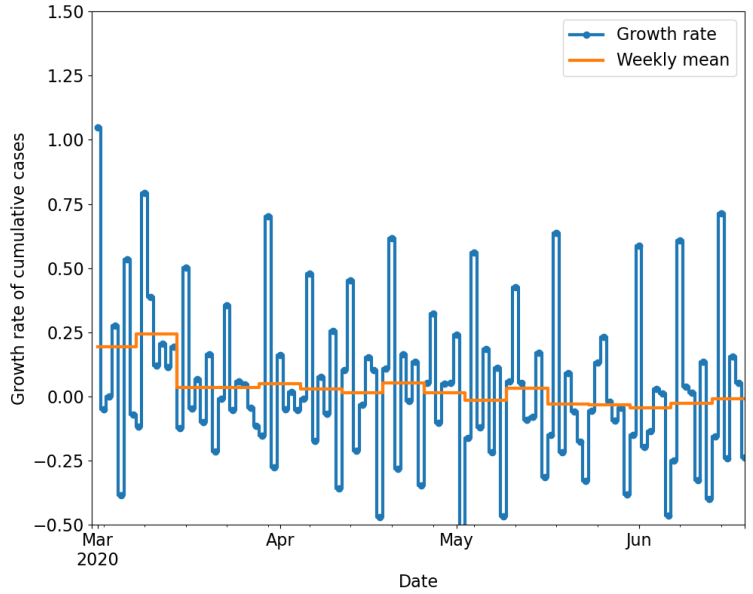


Weekly growth rate by date of onset

- Week before March 15 = 0.3
- Week after March 15 = -0.03 to 0.04

Crude reproductive number estimates

- 2.2 before March 15th
- 0.81 to 1.10 after March 15th



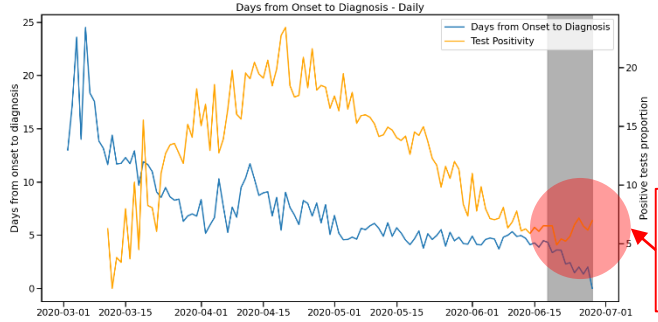
Estimating Effects of Better Detection

VDH data shows reductions in time from Symptom Onset to Diagnosis

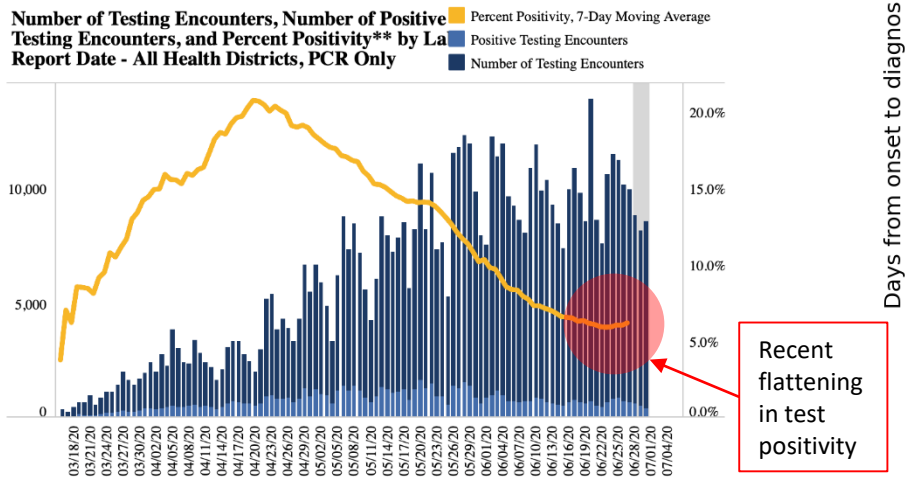
Days to Diagnosis drops ~40% in recent weeks

- Mid March to Late April = 7.8 days
- Late April to Mid May = 5.6 days (~30% lower)
- Mid May to mid June = 4.5 days (~45% lower)

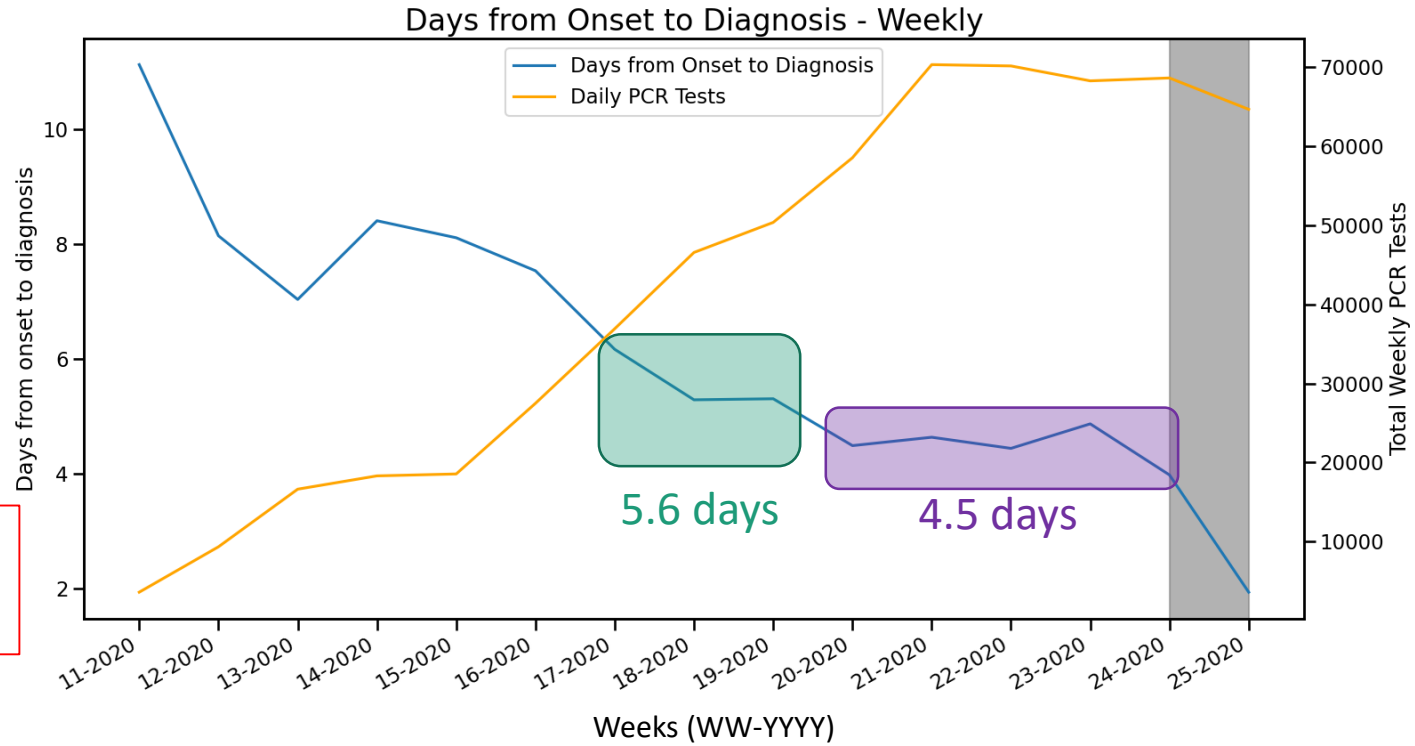
Test positivity vs. Onset to Diagnosis



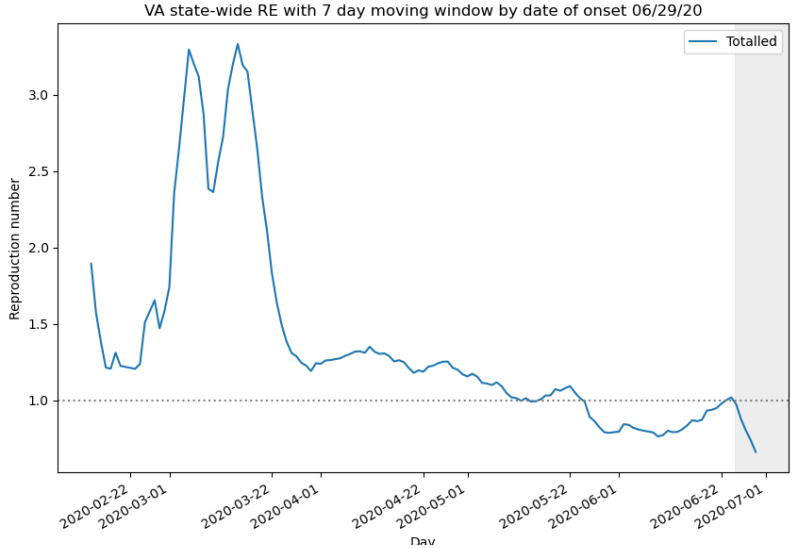
Testing Encounters increased, though slowing: ~30K/week (late April) to ~8K/day (early June)

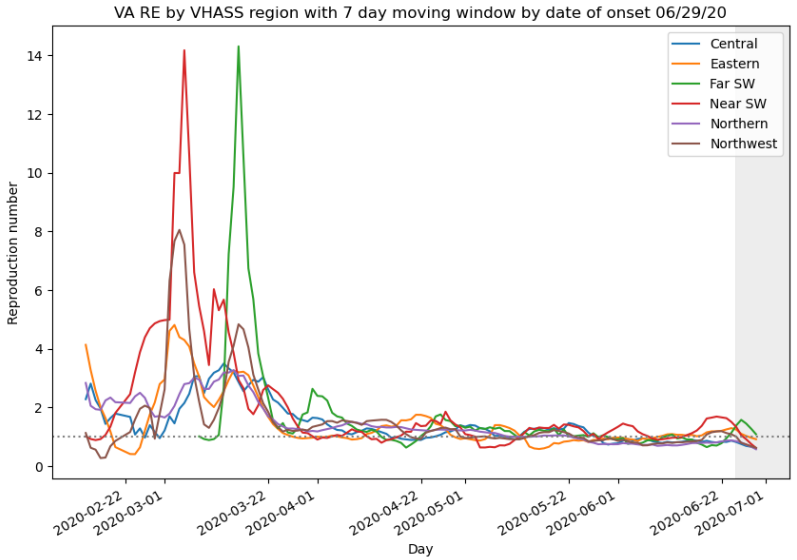


Accessed 10am July 1st, 2020
https://www.vdh.virginia.gov/coronavirus/



Estimating Daily Reproductive Number





Statewide and most regions follow similar pattern

- Spike, followed by a decline, to plateau, with recent upswing
- This week: overall decline, some regions up

Methodology

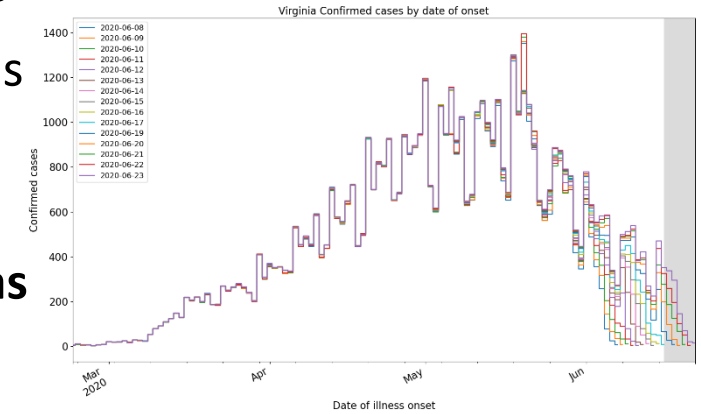
- Wallinga-Teunis method as implemented in EpiEstim[1] R package
- Based on Date of Onset of Symptoms
- Uses serial interval to estimate R_e over time: 6 days (2 day std dev)

Recent Estimates subject to revision as more data comes in

- Date of onset unstable in last 7-14 days

June 20th Estimates

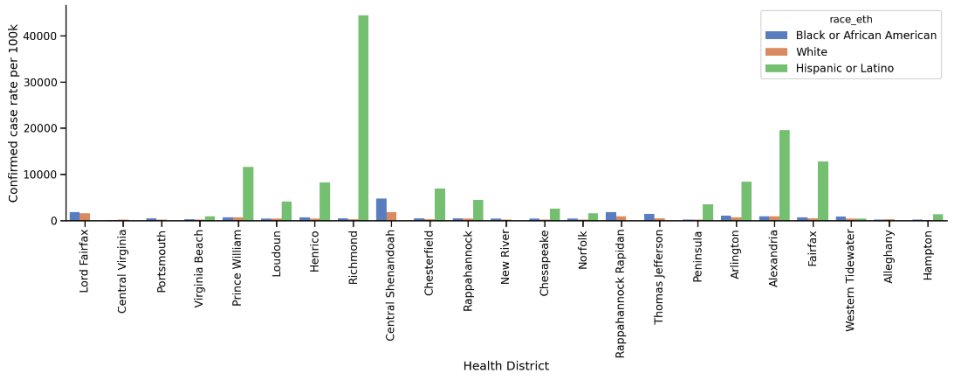
Region	Current R_e	Diff Last Week
State-wide	0.937	0.179
Central	0.822	0.027
Eastern	1.183	0.160
Far SW	0.712	-0.193
Near SW	1.651	0.684
Northern	0.791	0.130
Northwest	1.150	0.384



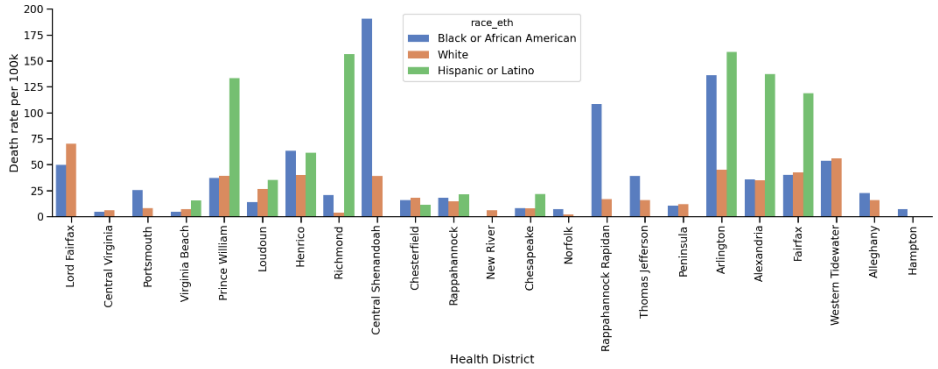
1. Anne Cori, Neil M. Ferguson, Christophe Fraser, Simon Cauchemez. A New Framework and Software to Estimate Time-Varying Reproduction Numbers During Epidemics. American Journal of Epidemiology, Volume 178, Issue 9, 1 November 2013, Pages 1505–1512, https://doi.org/10.1093/aje/kwt133

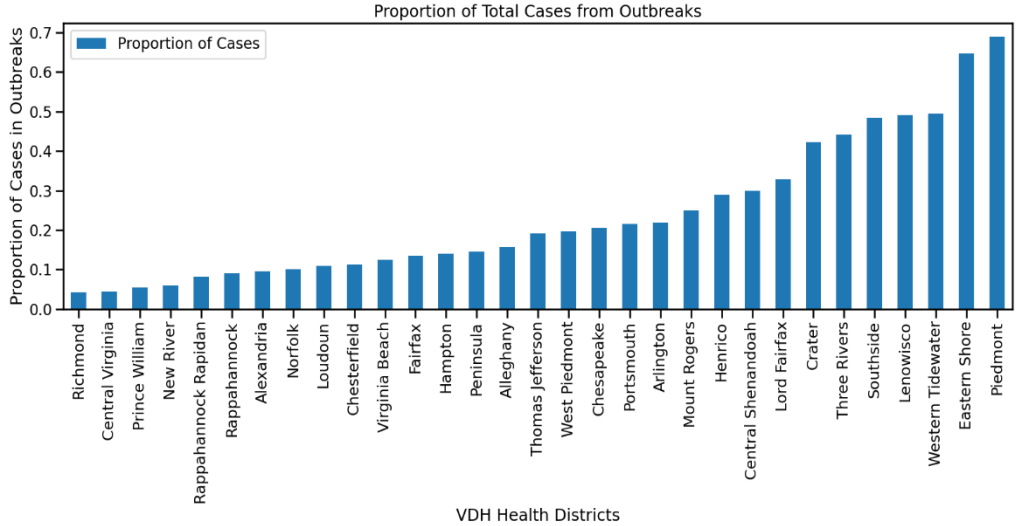
Impact of Race / Ethnicity & Outbreaks

Confirmed Case Rate



Death Rate





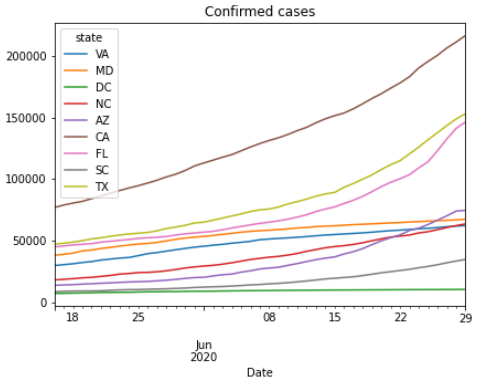
Different Races and Ethnicities disproportionally affected

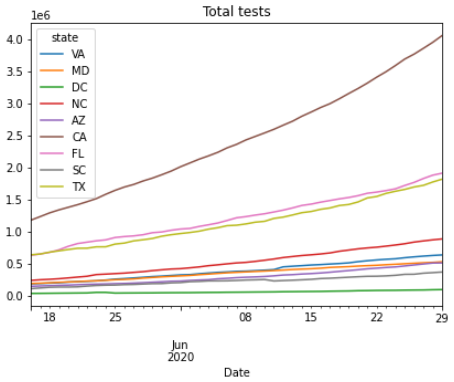
- Hispanic population bears large burden of disease compared to population size

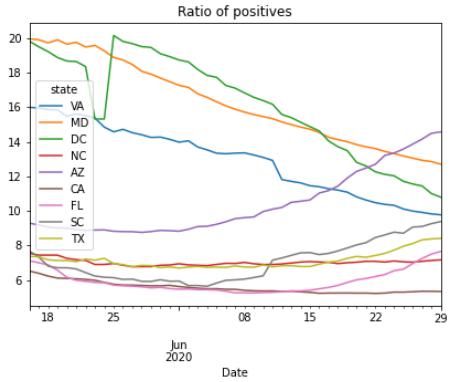
Outbreak Events are hard to predict and affect model fits

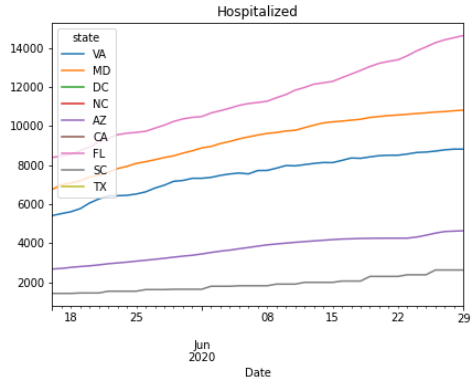
- Eastern Shore has 60% of cases from 10 outbreaks
- Fairfax most outbreaks but relatively low proportion

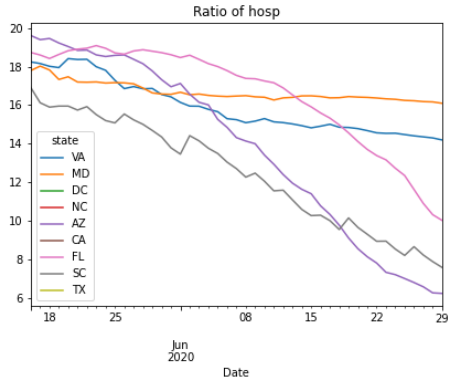
Other State Comparisons











Several States experiencing large surges in cases

- Most relaxed social distancing in early to mid May
- Following 4 - 6 week delay, there is a significant uptick

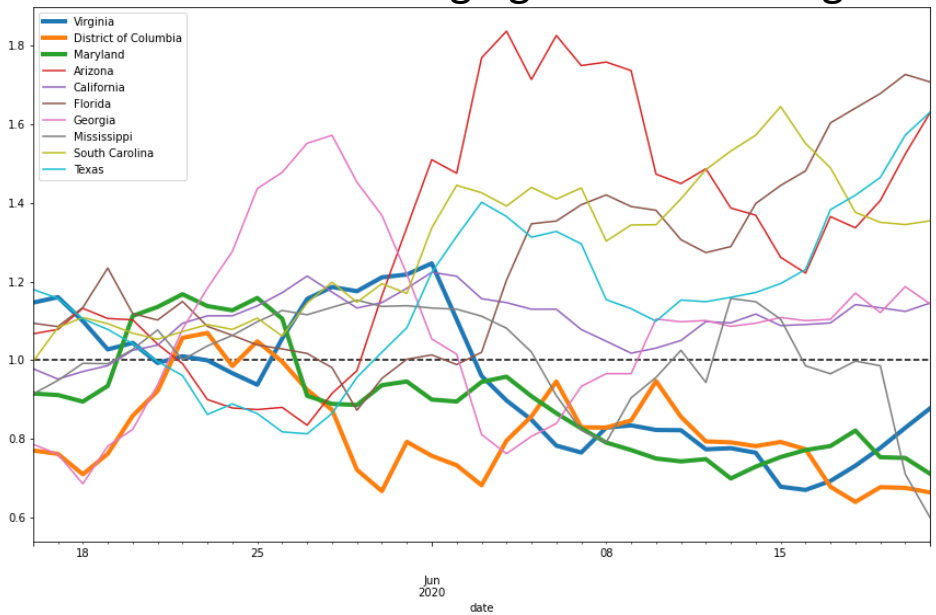
Estimated Rs experienced steady rise for several weeks

- Virginia's R remains stable with a recent upward trend

Virginia, Maryland, and DC remain steady

- All three are below 1.0 as they have been for several weeks
- States with resurgence have had R_e over 1.0 for several weeks

Estimated Re* for surging States and Neighbors



* Based on confirmed cases per day

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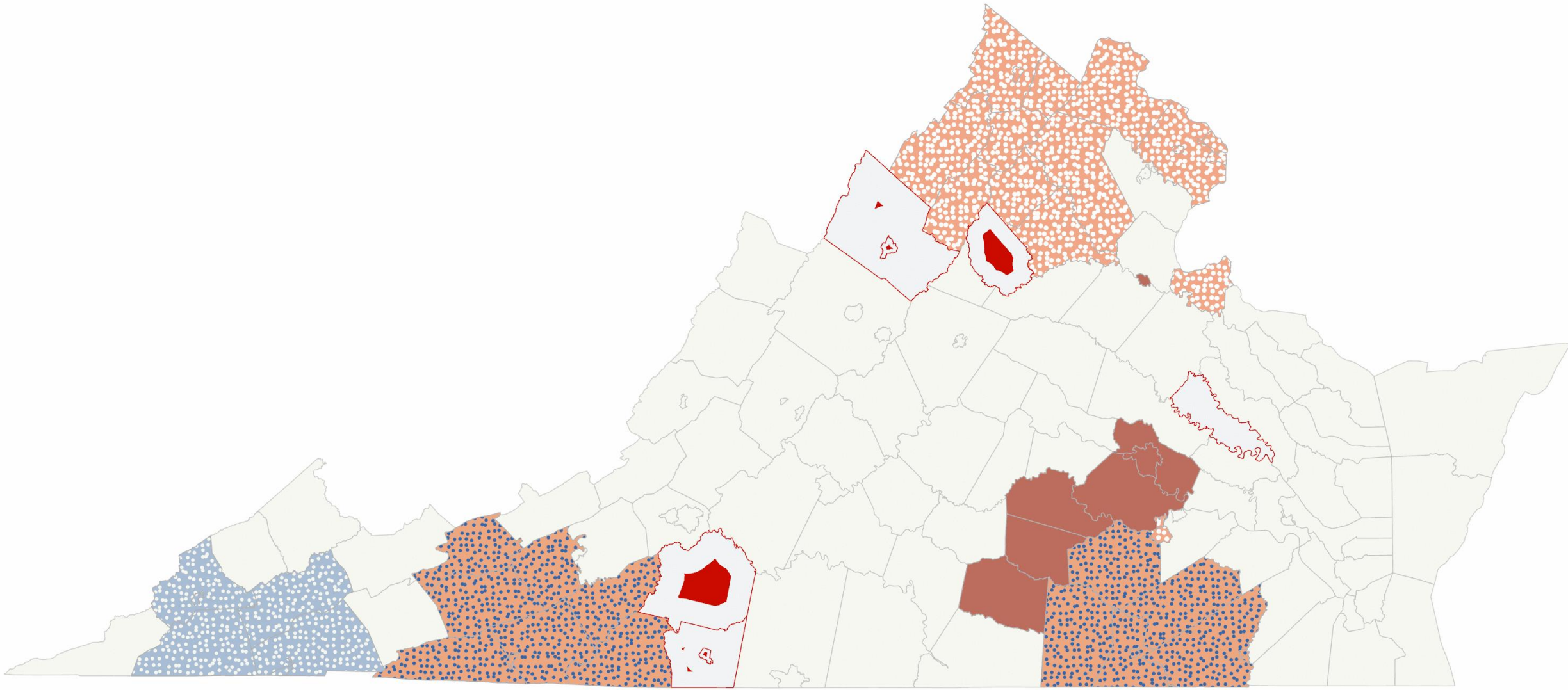
Emerging Hot Spot Analysis

No Pattern Detected	No significant patterns.	**Intensifying Hot Spot**	Significant hot spot for 90% of time, clustering increasing.	**Sporadic Hot Spot**	On-again then off-again hot spot.
New Hot Spot	Hot spot for final timestep, never significant before.	**Persistent Hot Spot**	Significant hot spot for 90% time, no change in clustering.	**Oscillating Hot Spot**	Hot spot in final step, history of being significant cold spot.
Consecutive Hot Spot	Single uninterrupted run of significant hot spot scores.	**Diminishing Hot Spot**	Significant hot spot for 90% of time, clustering decreasing.	**Historical Hot Spot**	No longer hot spot but was for 90% of time.

- Runs a Hot Spot Analysis at <u>each</u> time step
- Then a Mann Kendall Test on <u>each</u> county to detect temporal trends
- As with standard analysis, output is based on significance of clusters, not absolute values

Emerging Hot Spot Analysis for COVID19 Incidence
2020-03-01 to 2020-06-27 (weekly)



PATTERN

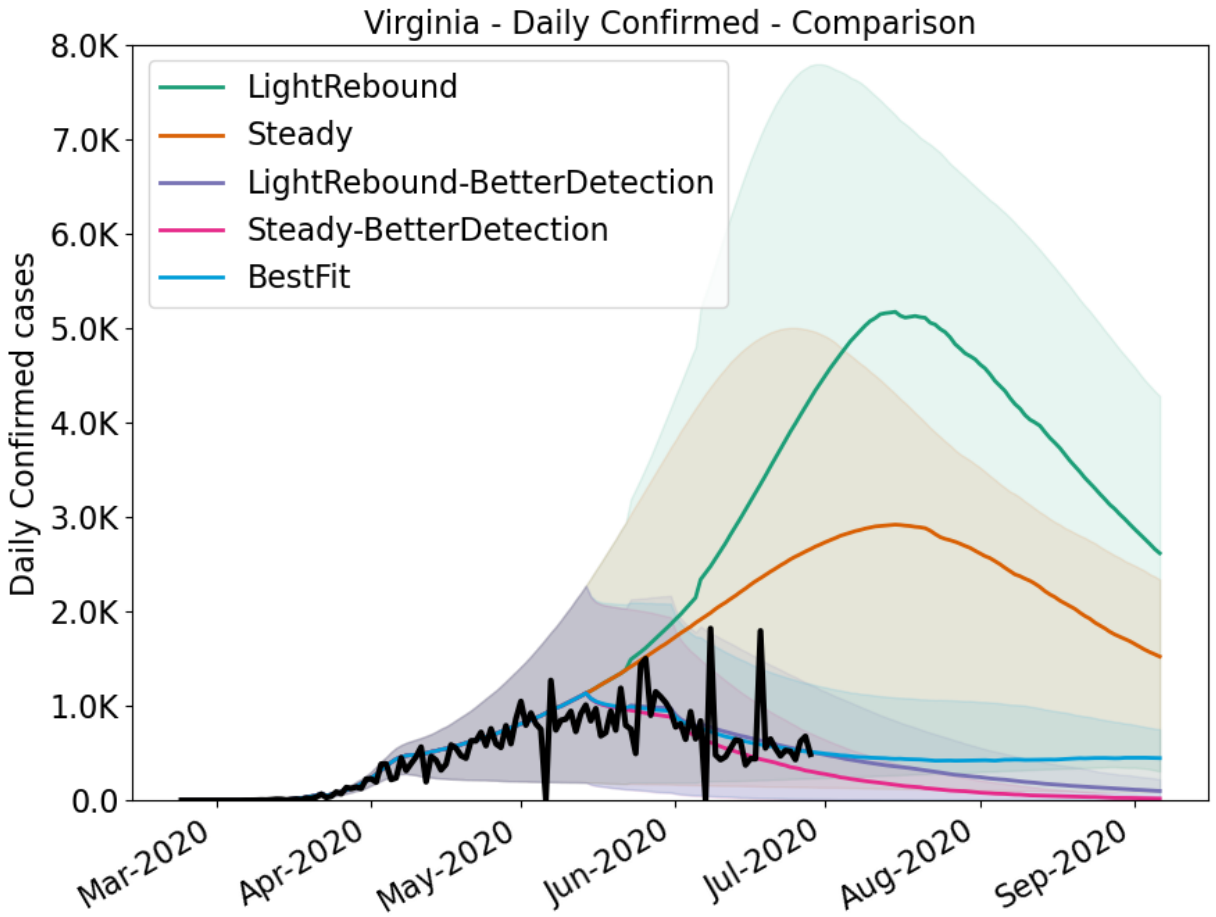
- New Hot Spot
- Consecutive Hot Spot
- Intensifying Hot Spot
- Persistent Hot Spot
- Diminishing Hot Spot
- Sporadic Hot Spot
- Oscillating Hot Spot
- Historical Hot Spot
- New Cold Spot
- Consecutive Cold Spot
- Intensifying Cold Spot
- Persistent Cold Spot
- Diminishing Cold Spot
- Sporadic Cold Spot
- Oscillating Cold Spot
- Historical Cold Spot
- No Pattern Detected

<all other values>

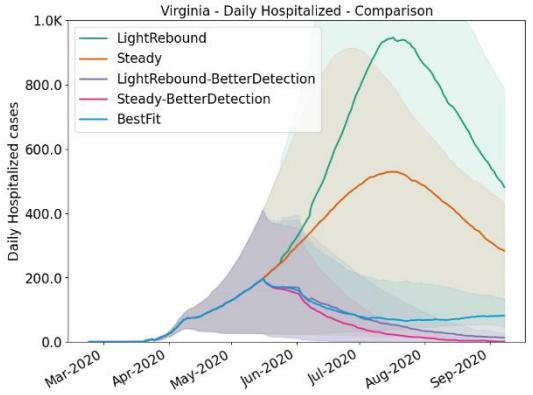
Model Results

Outcome Projections

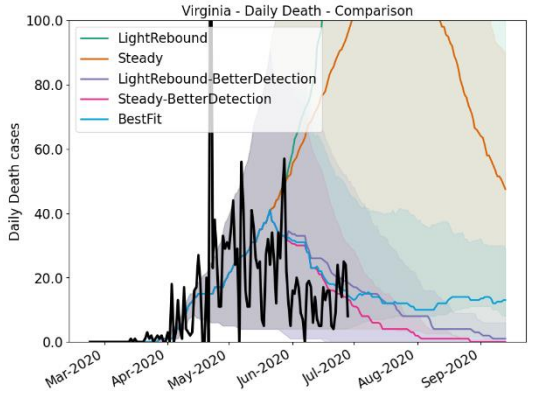
Confirmed cases



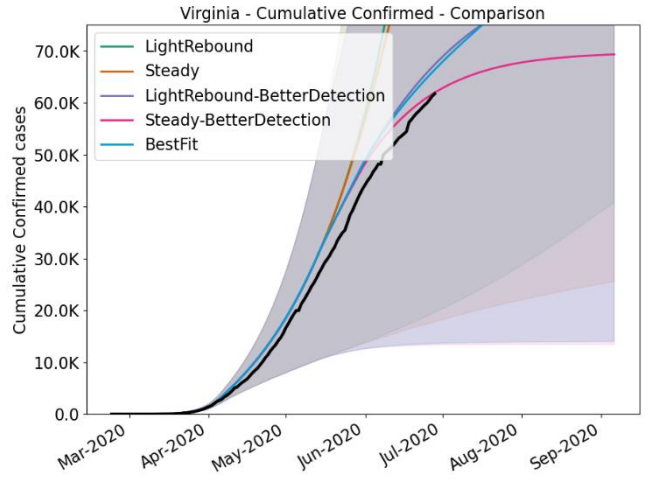
Hospitalizations



Deaths



Cumulative Confirmed cases



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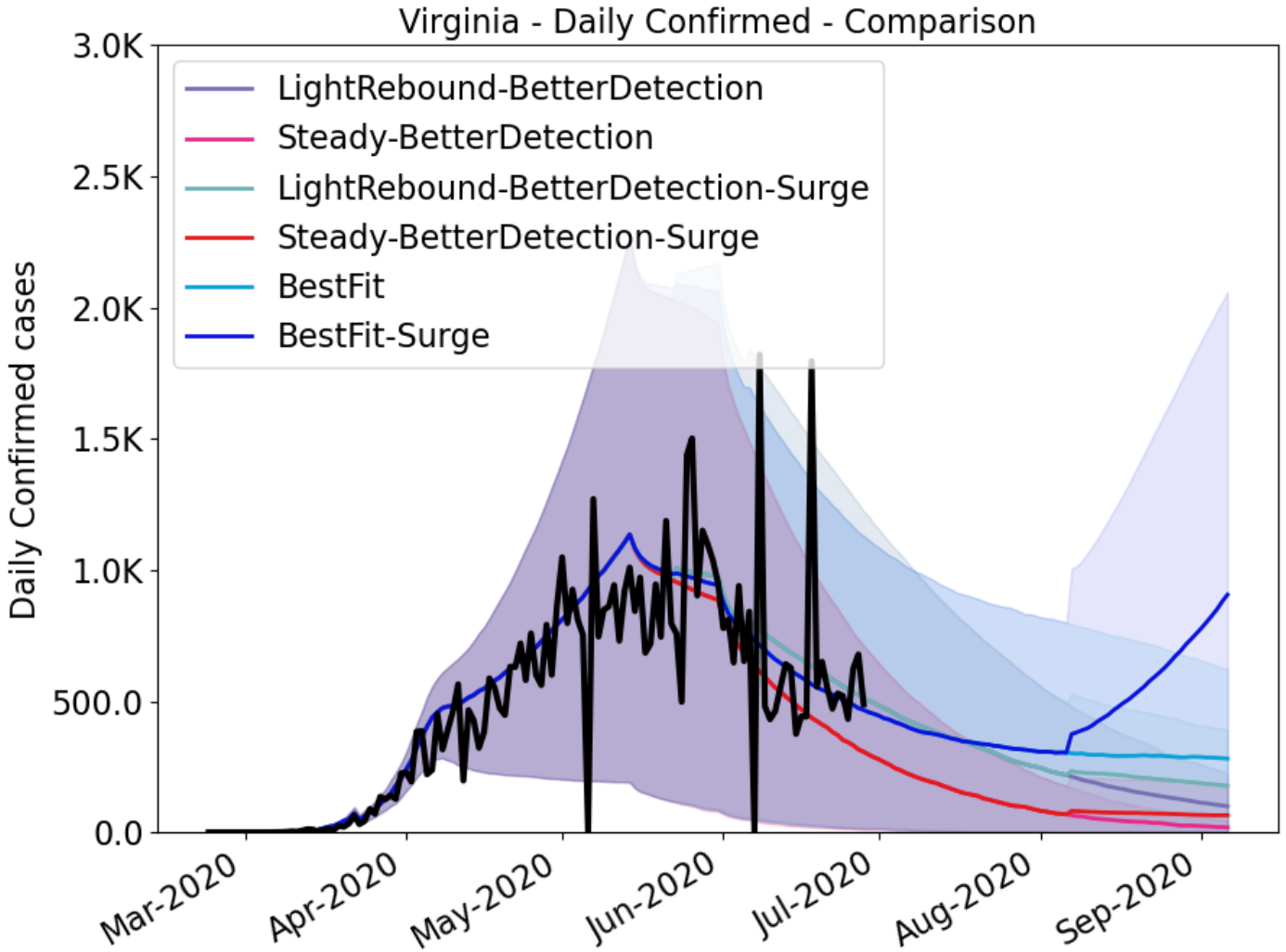
Outcome Projections – with Surge



Weekly New Confirmed Cases*

Week Ending	Best Fit	Best Fit w/ Surge
6/21/20	4,294	4,294
6/28/20	3,853	3,853
7/5/20	3,508	3,508
7/12/20	3,248	3,248
7/19/20	3,106	3,106
7/26/20	2,994	2,994
8/2/20	2,954	2,954
8/9/20	2,978	3,050
8/16/20	3,014	3,832
8/23/20	3,066	4,562
8/30/20	3,131	5,411
9/6/20	3,156	6,252

*Numbers are medians of projections

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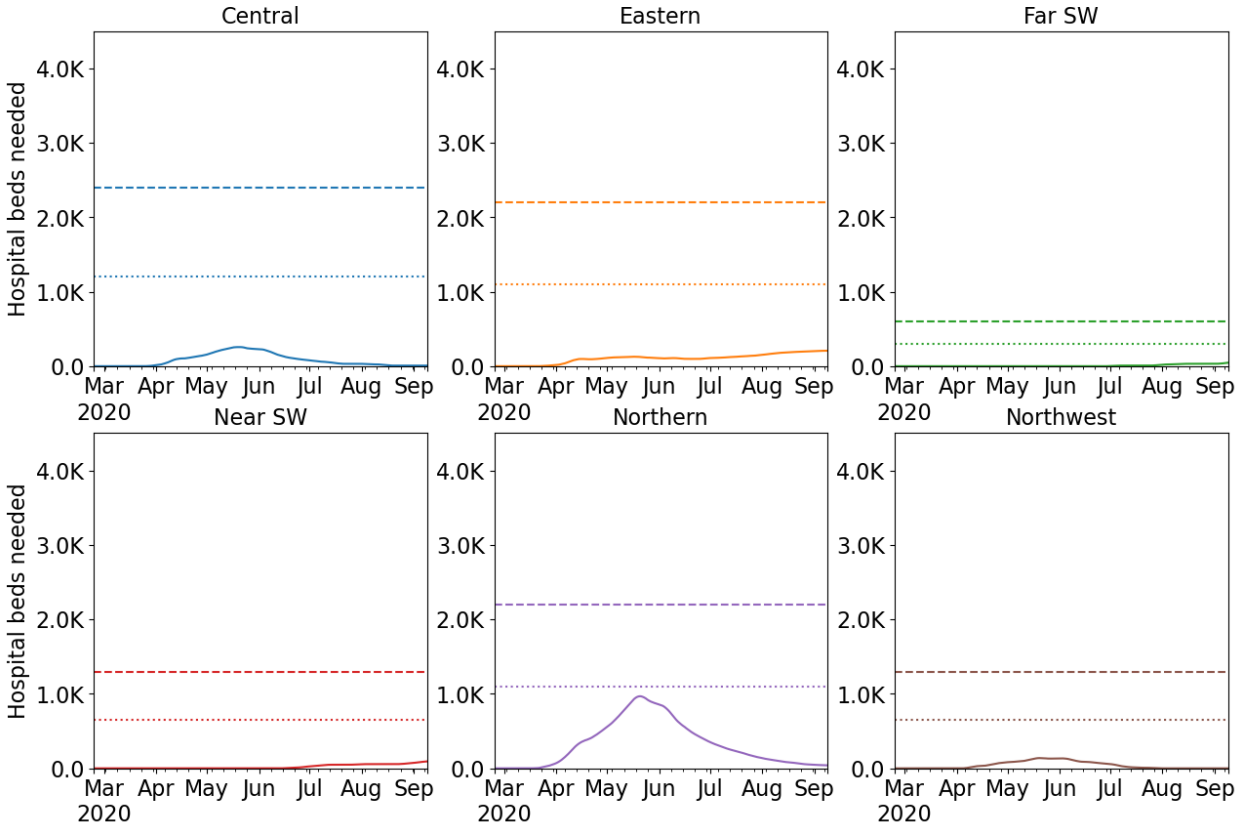
Hospital Demand and Capacity by Region

Capacities by Region – BestFit

COVID-19 capacity ranges from 80% (dots) to 120% (dash) of total beds



* Assumes average length of stay of 8 days

Date ranges when regions are estimated to exceed surge capacity

Scenario	**Date Ranges**
Light	Mid June to Mid Aug
Steady	Late June to Late July
Light – Better Detection	None
Steady – Better Detection	None
Best Fit	None

Social Distancing postponed the time to when capacity could be exceeded, additional controls continue to keep demand below capacity

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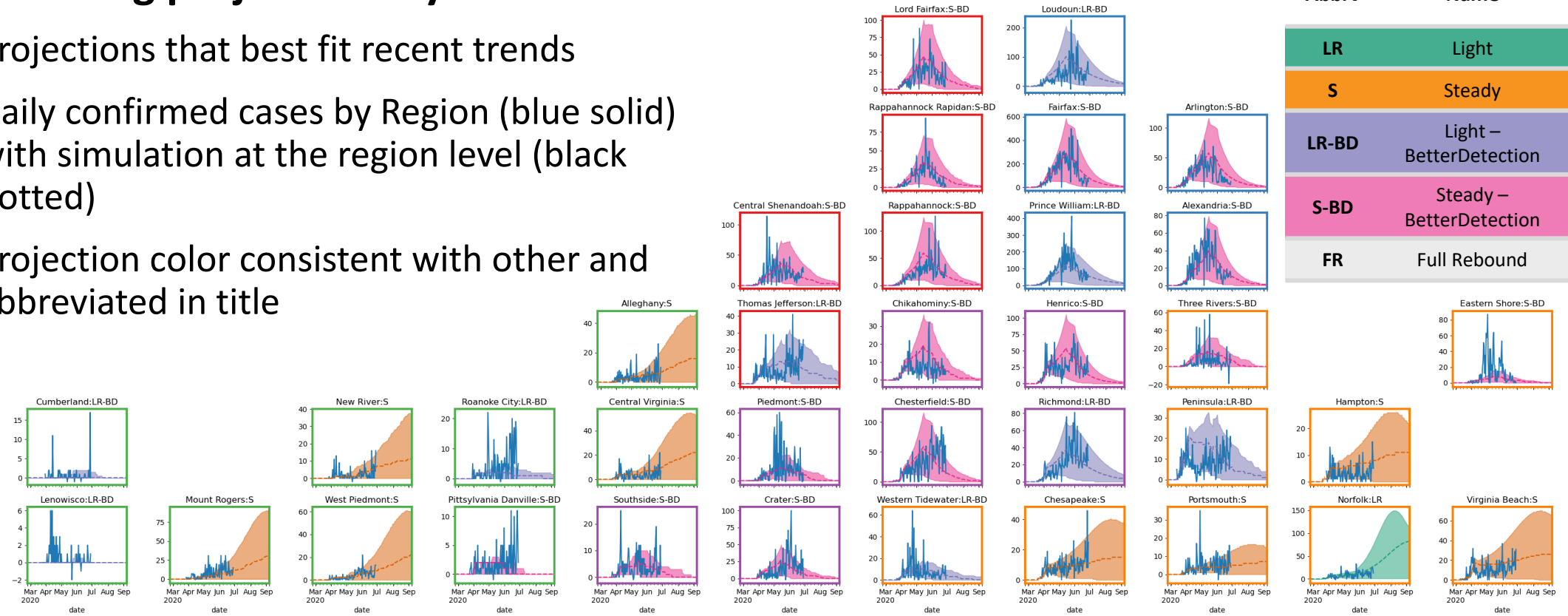
District Level Projections - Daily

Best fitting projections by District

- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

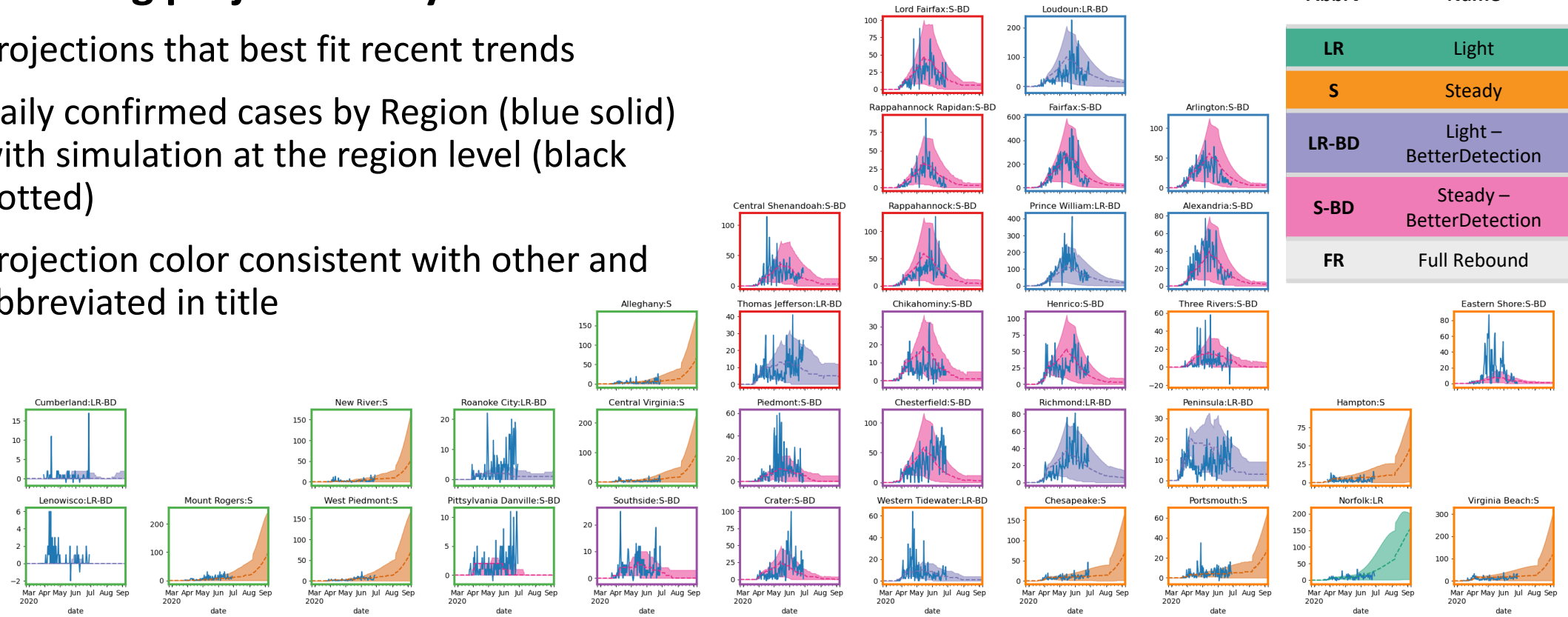


Abbrv	Name	# of Districts
LR	Light	1
S	Steady	9
LR-BD	Light – BetterDetection	9
S-BD	Steady – BetterDetection	16
FR	Full Rebound	0

District Level Projections – Daily with Surge

Best fitting projections by District

- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

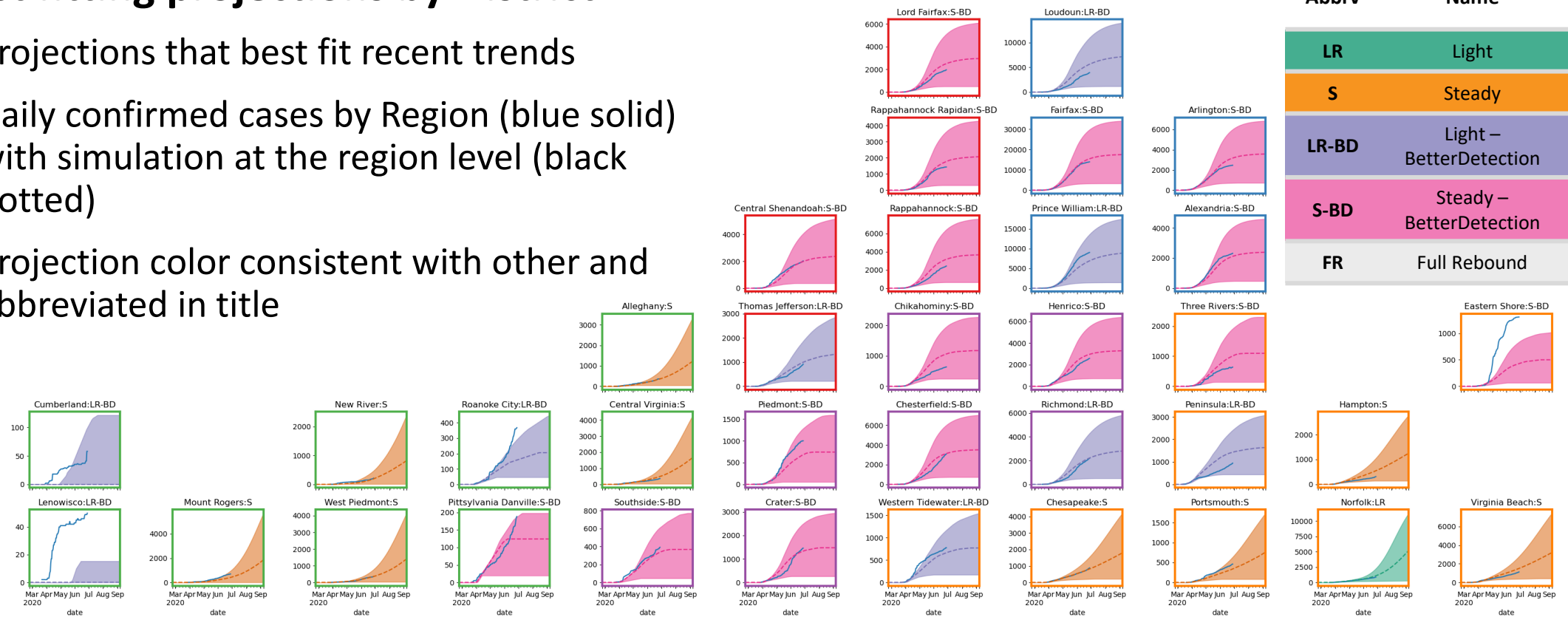


Abbrv	Name	# of Districts
LR	Light	1
S	Steady	9
LR-BD	Light – BetterDetection	9
S-BD	Steady – BetterDetection	16
FR	Full Rebound	0

District Level Projections – Cumulative

Best fitting projections by District

- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title

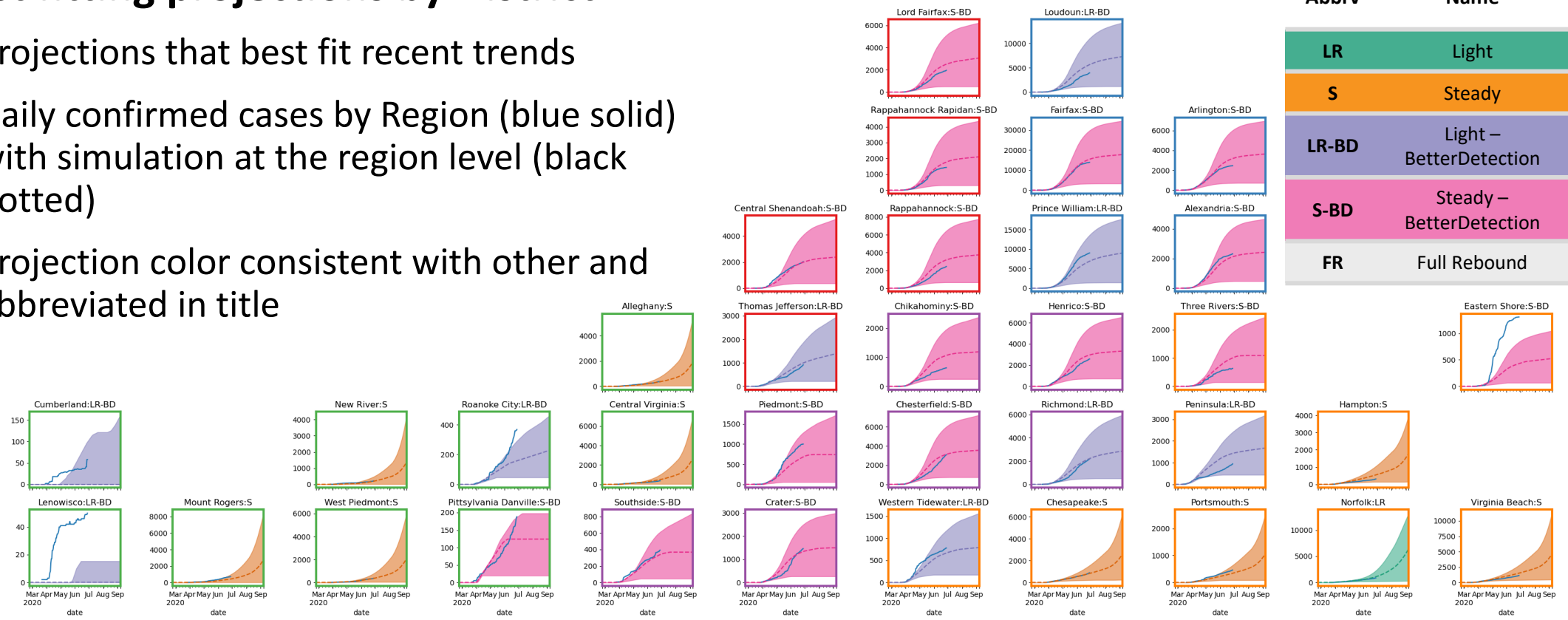


Abbrv	Name	# of Districts
LR	Light	1
S	Steady	9
LR-BD	Light – BetterDetection	9
S-BD	Steady – BetterDetection	16
FR	Full Rebound	0

District Level Projections – Cumulative with Surge

Best fitting projections by District

- Projections that best fit recent trends
- Daily confirmed cases by Region (blue solid) with simulation at the region level (black dotted)
- Projection color consistent with other and abbreviated in title



Abbrv	Name	# of Districts
LR	Light	1
S	Steady	9
LR-BD	Light – BetterDetection	9
S-BD	Steady – BetterDetection	16
FR	Full Rebound	0

Key Takeaways

Projecting future cases precisely is impossible and unnecessary.
Even without perfect projections, we can confidently draw conclusions:

- **Virginia continues to maintain control as many areas of the country are entering a period of resurgence, however, there are signs of growth as some health districts have increased activity.**
- Model updates this week:
  - Added a scenario showing a potential resurgence of cases
  - Identified “Best fitting” scenarios district by district which match their recent trends and added a combined state level “Best Fit” scenario representing this combination
  - Updated additional analyses to inform restructuring of model for next phase of epidemic
- Other states showing rapid rise following relaxation of social distancing with limited control measures.
- The situation is changing rapidly. Models will be updated regularly.

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Cuebiq: COVID-19 Mobility insights. https://www.cuebiq.com/visitation-insights-covid19/

Biocomplexity page for data and other resources related to COVID-19: https://covid19.biocomplexity.virginia.edu/

Questions?

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Supplemental Slides

Recent Parameter Validation

New York State announced sero-prevalence survey results on May 2nd

- 15,000 antibody tests conducted randomly through the state at grocery stores
- **Total Attack Rate**: 12.3%

Estimation of undetected infections

- Total infections in NY = 2.46M, total of 300K confirmed cases
- Confirmed case detection = 12% of infections (close to 15% used in model)

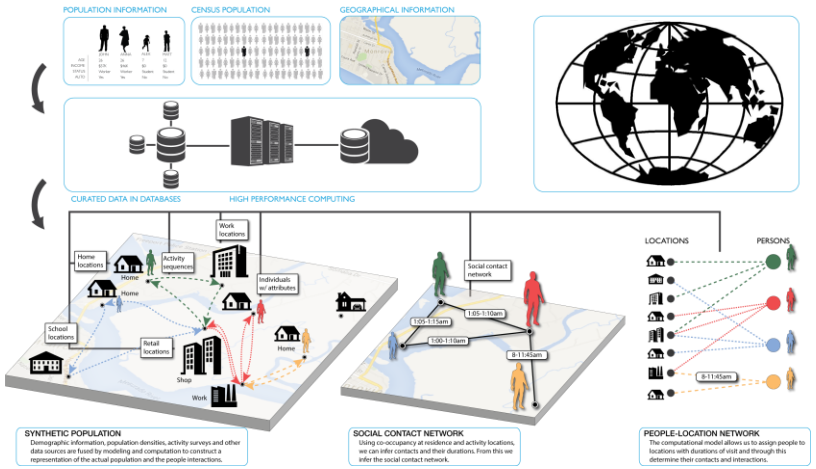
Estimation of hospitalizations from infections

- Total infections in NY = 2.46M, total of 66K hospitalizations
- Hospitalizations = 2.7% of infections (close to 2.25% used in model)

Agent-based Model (ABM)

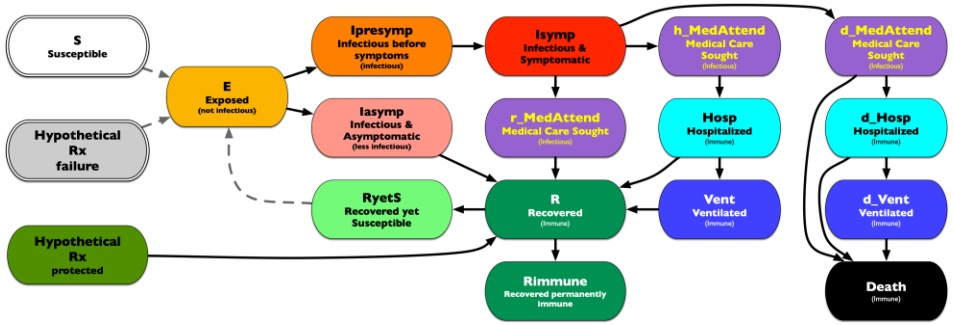
EpiHiper: Distributed network-based stochastic disease transmission simulations

- Assess the impact on transmission under different conditions
- Assess the impacts of contact tracing



Synthetic Population

- Census derived age and household structure
- Time-Use survey driven activities at appropriate locations



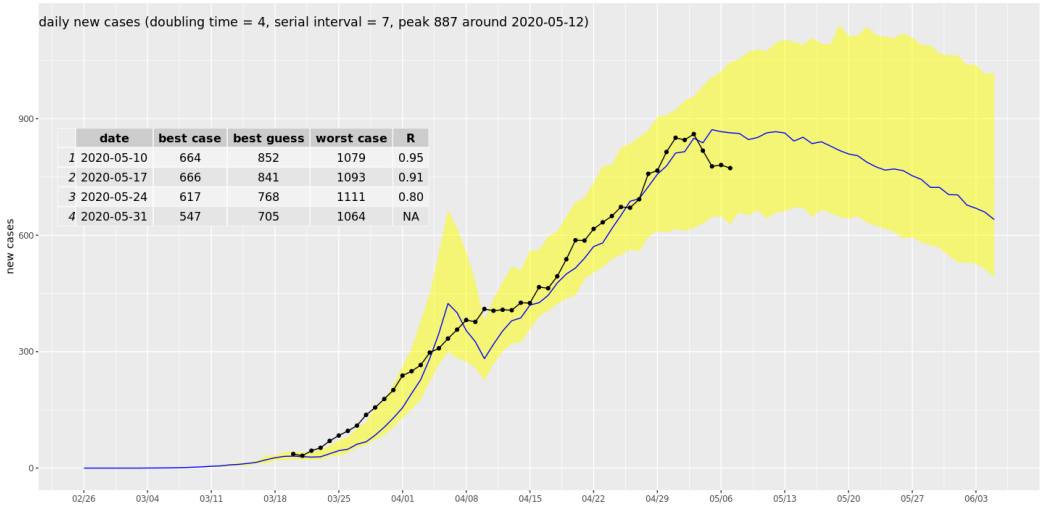
Detailed Disease Course of COVID-19

- Literature based probabilities of outcomes with appropriate delays
- Varying levels of infectiousness
- Hypothetical treatments for future developments

ABM Social Distancing Rebound Study Design

Study of ”Stay Home” policy adherence

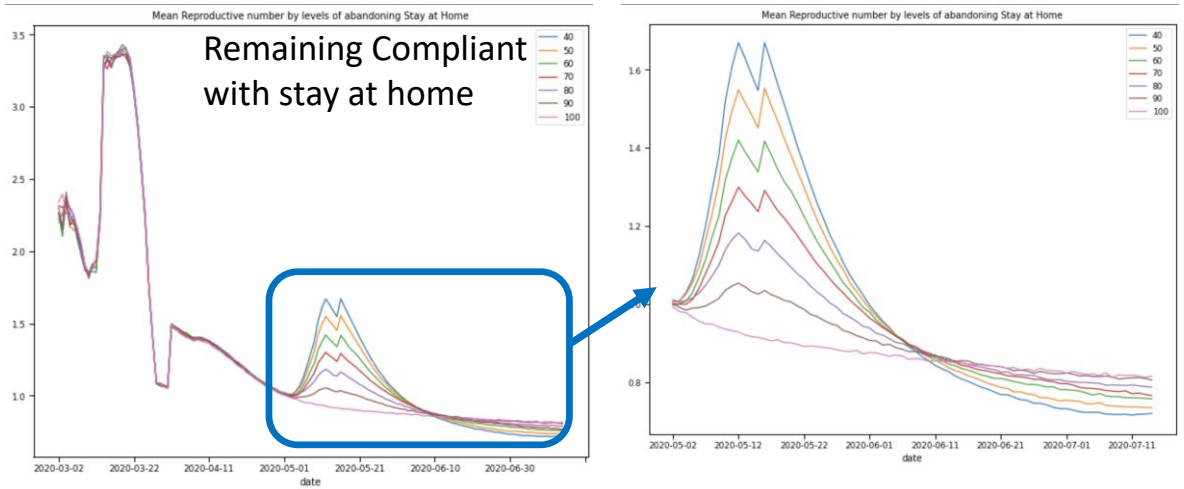
- Calibration to current state in epidemic
- Implement “release” of different proportions of people from ”staying at home”



	date	best case	best guess	worst case	R
1	2020-05-10	664	852	1079	0.95
2	2020-05-17	666	841	1093	0.91
3	2020-05-24	617	768	1111	0.80
4	2020-05-31	547	705	1064	NA

Calibration to Current State

- Adjust transmission and adherence to current policies to current observations
- For Virginia, with same seeding approach as PatchSim

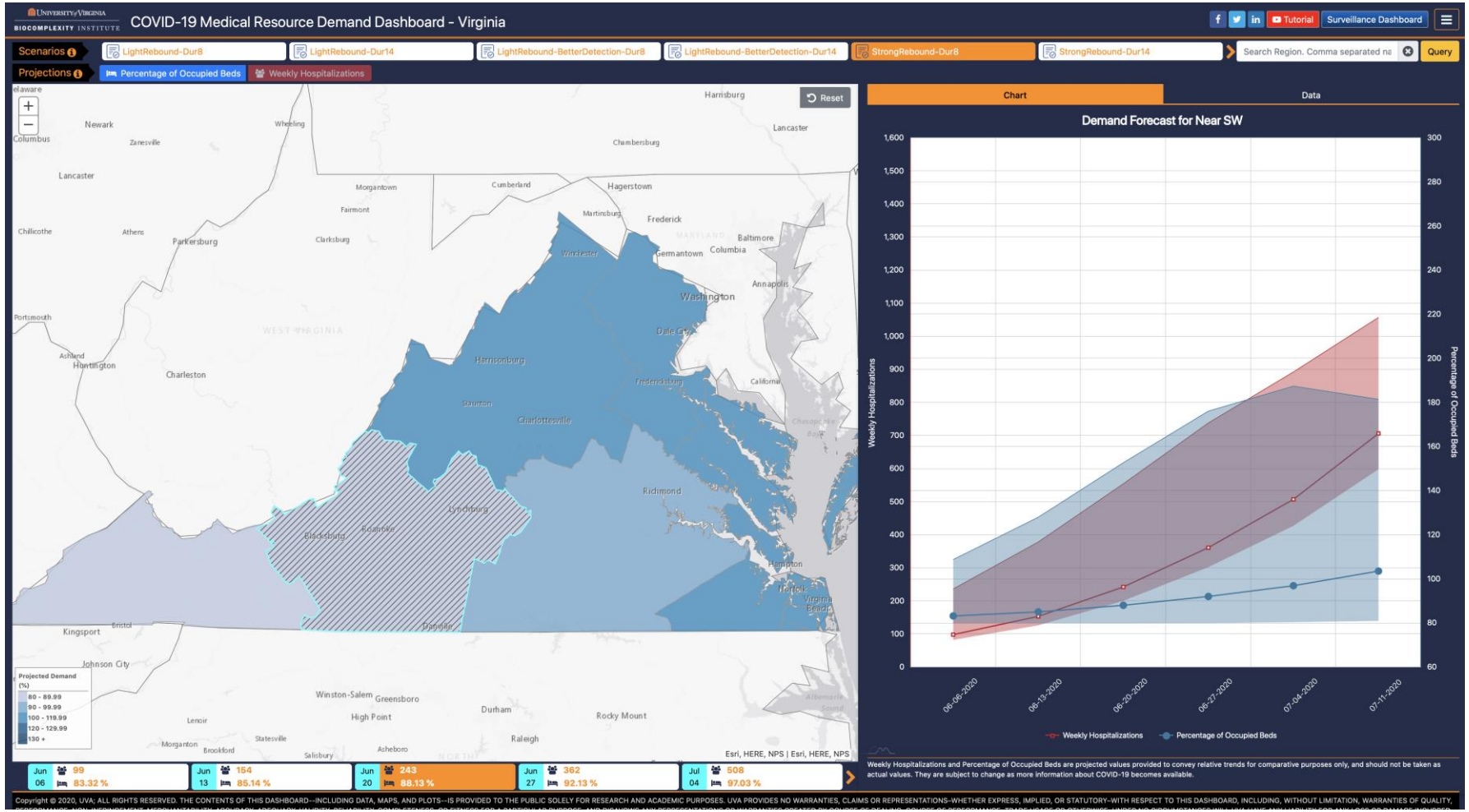


Impacts on Reproductive number with release

- After release, spike in transmission driven by additional interactions at work, retail, and other
- At 25% release (70-80% remain compliant)
- Translates to 15% increase in transmission, which represents a 1/6th return to pre-pandemic levels

Medical Resource Demand Dashboard

https://nssac.bii.virginia.edu/covid-19/vmrddash/



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